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Managing the Health Impacts of Waste Incineration

The current framework used to assess health effects from incinerators considers local populations but often excludes workers and regional populations

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Abstract

Incineration has emerged over the last century as a viable strategy for (a) reducing the volume of municipal waste, (b) for reducing substantially the volume of chemical and biological hazardous wastes, (c) for destroying medically contaminated hospital waste, and (d) for producing energy. Facing an exponential rise in garbage production, policy-makers in the US selected waste incineration in the 1970s as a waste-management option. By that time European nations had already made a strong commitment to waste incineration. Waste incineration has been employed in some form for centuries. However, in the last several decades, the quantity of material combusted, public concerns about the health and ecological impacts of combustion facilities, the level of environmental control, and the cost of

control have all increased. Whether waste incineration poses a health risk has been the subject of continuous scientific debate.

Introduction

In November 1999, the National Research Council released a report titled "Waste Incineration and Public Health" that addressed pollutant emissions, exposures and health risks from waste incineration (1). We both served as members of the committee that produced this report. In this paper our goal is provide some background both on the health issues that have emerged for waste incineration and to discuss some of the issues raised in the NRC report. Although the NRC report serves as an important reference for our discussion here, this paper represents our own views and is not intended to be the consensus view of the committee.

In spite of the great effort that has been devoted to health evaluations of incinerator emissions, NRC study identified both critical data limitations of and key inadequacies in the current health assessment framework. There are two areas in which the limitations and uncertainty in the data impact health effects assessments. First, there is very little emissions data for any event other that normal operations. Second, we still lack data needed to characterize intermedia transfers of emitted chemicals from ambient air to food webs and to indoor environments. Furthermore, we note that the existing framework used to assess human exposures and health effects from incinerators has focused on local populations but excluded both workers and the larger regional populations.

Waste Management, Incineration, and Public Health: The Burning Issues

There are hundreds of incinerators in the United States, including industrial kilns, boilers, and furnaces that are use to burn municipal solid waste (MSW) and hazardous waste. There are more than a thousand incinerators that have been used to burn medical waste. Per-capita production of MSW in the US has grown from 1.2 kg/day in 1960 to almost 2 kg/day in 1996 (1). Although per capita waste generation has slowed in the 1990s, waste production continues to rise as a result of population growth. It is estimated that some 3 million tons of hazardous waste is burned annually in the US (1). There are roughly 150 commercially-, privately- and/or government-operated hazardous-waste incinerators in the US as well as an unknown number of industrial boilers or furnaces and cement or aggregate kilns currently accepting hazardous waste for combustion. Hospitals, which can generate about 12 kg of waste per bed per day, are the largest producers of medical waste (1). About 15% of the hospital waste is "red bag" waste that is incinerated or otherwise sterilized to prevent the spread of disease. Currently, a rising fraction of medical waste is being burned in municipal waste incinerators. **Figure 1** illustrates among these three incinerator categories the relative quantities of waste generated and waste combusted as well as the number of operating facilities.

Emissions from all incinerators are subject to regulations promulgated through the 1990 Clean Air Act (CAA). Regulations developed under CAA are intended to limit atmospheric concentrations of six criteria pollutants as well as the 188 hazardous air pollutants (HAPs)[1]. The CAA requires the U.S. EPA to establish source performance standards for new incinerators and emissions guidelines for existing facilities. These changes moved regulations from the prior risk-based emissions standards for HAPs to technology-based standards. In response, the EPA has defined maximum-available-control-technology (MACT) standards for incinerators and other HAPs sources. MACT standards require all pollutant sources within a category (such as incinerator sources) to attain a level of control that reflects the average of the best-performing facilities (top 12%) in that category. The residual risk remaining after MACT must also be assessed and be found below a target level. The NRC study noted that MACT standards are intended to address local problems, but they may not be sufficient to protect workers and regional populations. As illustrated in **Figure 2** many exposures to incinerator pollutants can have both a local and a regional sphere of impact. For an impacted population, the magnitude of cumulative exposures to incinerator pollutants depends both on proximity to the nearest incinerator and on the number of incinerators and other combustion sources releasing that pollutant into a region. The relative magnitude of local and cumulative exposures depends on the persistence and transport range of the pollutant (2).

Assessing the health effects of incinerators requires integration of many different kinds of information. First we must identify the types of pollutants that will be produced as a result of the waste combustion. These agents must be characterized by their toxicity and chemical properties. Next, we must determine rates and location

[1] The six criteria pollutants are carbon monoxide, lead, nitrogen dioxide, ozone, particulate matter, and

of emissions and where these pollutants go. Some are released inside the waste facility itself, many are filtered out in the pollution control equipment and then go to a landfill, and some are released to the environment from a stack. For each emission, (i.e. inside the building, up the stack, into a landfill, etc.) we need to know where and how the released pollutants spread, transform, and accumulate within the environment. To assess any potential human health effects, we must characterize human contact with waste products and with air, water, soil, and food that have been impacted by these releases. Finally, to assess risk, we must compare any observed or predicted exposures to those exposures associated with adverse health effects.

What Goes in, What Comes Out?: Controlling the Products of Combustion

Modern incinerators are highly efficient and relatively clean systems for reducing the volume of wastes. There are three by-products streams from an incinerator--the stack emissions, the ash residue, and the residues from the pollution control equipment. The largest volume of material released from an incinerator is the stack-gas stream, which contains mostly carbon dioxide and water vapor with small amounts of particulate matter and pollutant vapors. Many potentially harmful substances are detected in the gaseous and particulate emissions from waste incineration. Among these emissions are fine particulate matter; acid gases; oxides of carbon, nitrogen, and sulfur; dioxins, furans, and other chlorinated compounds; metals; and polycyclic aromatic hydrocarbons (PAHs). Many of the organic

sulfur dioxide. The list of 188 hazardous air pollutants is published by the EPA Office of Air and compounds in the stack and waste residue are products of incomplete combustion (PICs) whose rate of production is controlled by combustion conditions.

Incinerators are combustion devices and to understand the variation of incinerator emissions, it is of value to compare them to another more familiar combustion device--the automobile engine. It is well known that the major fraction of auto emissions comes during start-up and during the periods when the auto is speeding up and slowing down (i.e. stop-and-go traffic). A well-tuned auto moving at freeway speed puts out few emissions. Similarly, a modern "well-tuned" incinerator operating with a constant and uniform feed puts out very low levels of pollution. A "well-tuned" incinerator is one that maintains combustion conditions at the appropriate temperature, residence time, and turbulence. Ideal combustion conditions are needed to maximize the destruction of PICs and minimize the partitioning of heavy metals in the vapor and particle-phase emissions that go out the stack. But during start-up and during transient events, ideal conditions are unattainable and pollution emissions can increase significantly. As with an automobile, air-pollution control devices can greatly reduce pollutant emissions, but equipment failures here can also result in significantly increased pollutant emissions. Understanding the cumulative emissions of an incinerator requires knowing how much "stop and go" operation takes place. Medical incinerators tend to produce a larger fraction of pollutants per unit mass of waste combusted in part because of these incinerators are operated in a "start and stop" mode. An extreme example of this problem is the large

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Radiation.

release of dioxins and furans from backyard incinerators, simple metal barrels in which people burn garbage (3). Despite the importance of emissions from intermittent cycles and from non-routine events, virtually all emissions data used to evaluate health impacts of incinerators are derived from routine operations.

Incineration also produces potentially toxic solid wastes. This includes the residual ash collected from the furnace as well as the solid waste from precipitators and scrubbers. This solid waste must be placed in landfills. It contains quantities of heavy metals, such as lead, cadmium, and mercury and may contain many of the less volatile PICs. This ash waste is more toxic than ordinary domestic refuse, and disposal is particularly expensive.

Emissions, Transport, and Exposure

For those who evaluate patterns of human exposures to incinerator emissions, the most important and difficult task is to track the concentration and movement of, and changes that occur in, the contaminants as they move through the environment from the incineration facility to a point of contact with people. Most pollutants released from incinerators are stack emissions to the atmosphere, where they partition among the gas and particulate components. This partitioning affects downwind transport and deposition. As the pollutants spread through the air, workers at the incinerator and people who live close to an incinerator can be exposed directly through inhalation or indirectly through ingestion of locally-produced foods or water contaminated by deposition of the pollutants to soil, vegetation, and surface water.

Populations that live at some distance from the incinerators are exposed through a different mix of environmental pathways. At these distances, pollutants have sufficient time to go through various chemical and physical transformations and pass into and out of soil, vegetation, and surface water. For the more persistent pollutants, exposures at regional scales through contact with water, food, soil, and house dust appear to be the most important exposure pathways. But the multimedia, multipathway exposures remain poorly characterized. There is a continuing absence of scientific studies, of models, and of direct measurements of human contact for these indirect pathways.

An obstacle to regional-scale health assessment is the low reliability of both measured data and models used to determine indirect exposures and intermedia transfer factors (ITFs) in particular. This issue is discussed in the NRC report and also in current literature (1, 4, 5). ITFs express the ratio of concentration in one environmental medium to another or in an exposure medium relative to an environmental medium (5). Examples of ITFs are water/air, soil/air, vegetation/air, vegetation/soil, indoor/outdoor air, etc. partition ratios. There are a number of ITFs needed for assessing source/dose relationships for incinerator emissions.

Health Effects

Historically, the principal health concerns for waste incineration were focused primarily on those in communities near the incinerator. However, the NRC report identified three potentially exposed populations (1). These are

(1) the local population, which is exposed primarily through inhalation of airborne emissions;

(2) workers at the facility, especially those who clean and maintain the pollution control devices; and

(3) the larger regional population who may be remote from any particular incinerator, but who consume food potentially contaminated by one or more incinerators and other combustion sources that release the same persistent and bioaccumulative pollutants.

Workers

Workers come into close contact with not only the stack emissions, but also with toxic pollutants captured in the air pollution control equipment, including electrostatic precipitators and bag houses. These must be cleaned out periodically, and high concentrations of dioxin and various metals have been measured in the air during these operations. Both personal and area sampling of workers cleaning out electrostatic precipitators at municipal incinerators demonstrated exposures greatly in excess of recommended limits for dioxins and metals (arsenic, lead, cadmium and aluminum) (1, 6). Elevated levels of dioxin and lead have been reported in the blood of municipal incineration workers (1,7). Higher concentrations of hydroxypyrene in the urine of municipal incineration workers (8) indicate exposure to higher levels of polycyclic aromatic hydrocarbons; similarly, higher levels of urinary mutagens have been reported among refuse incinerator workers (9). Results such as these led the

NRC committee to express substantial concerns about incinerator workers' exposures to dioxin, lead, mercury, other metals, and particulate matter, and a moderate degree of concern about their exposures to acidic aerosols and acidic gases. Because the MACT standards proposed by EPA are intended to reduce emissions from the facility but not change the work conditions, concern for workers will not diminish after implementation of MACT.

Regional versus Local Health Impacts

Adverse health effects of lead and particulate matter (PM) are now reported at levels previously thought to be safe. These pollutants can be produced by multiple existing sources in communities where incinerators are sited. The NRC committee expressed a substantial degree of concern about potential adverse health effect of these pollutants in communities near incinerators. However, because implementation of MACT should reduce these emissions substantially, the committee expressed only minimal concern for release of lead and PM from incinerators operating under MACT. Similarly, the committee's moderate degree of concern about the emissions of mercury and other metals reduces to a minimal degree of concern with MACT. Overall, the committee expressed negligible to minimal concern about the potential health effects on local communities from incinerators operating under MACT.

On a more regional level, airborne concentrations of incinerator pollutants will be quite low. However, the transport of persistent pollutants from multiple incinerators and other combustion sources can result in elevated concentrations of these pollutants in terrestrial and aquatic food over a wider geographic area. These considerations led the committee to have substantial concerns about the health effects of incinerator-generated dioxin, and a moderate degree of concern about incinerator generated lead, mercury, and other metals, on a regional population. The committee did not judge that MACT would reduce these elevated levels of concern (1).

Uncertainties about Exposures and Health Effects

Characterizing health impacts from incinerators involves the use of large amounts of data coupled with the use of models. Because these data and models must be used to characterize individual behaviors, engineered system performance, contaminant transport, human contact and uptake, and dose among large and often heterogeneous populations, there is large variability and uncertainty associated with these evaluations. The NRC committee identified the issues of uncertainty and variability as having both scientific and policy implications for attributing health impacts to incinerators. In particular, the committee noted that when the uncertainty and variability become large, it becomes difficult for the stakeholders to interpret or assign relevance to the estimated magnitude of exposure and health risk.

In the current framework for assessing health impacts, key uncertainties derive from factors that are excluded and from a lack of scientific data or understanding. As noted above, a case where uncertainty derives from exclusion is a health characterization based only on normal operating conditions. Because no data were available to evaluate emissions during start up and upset conditions, which can be much higher than normal operations, it is not yet possible to evaluate the exposures and consequent potential health risks during these conditions. Examples of where limited scientific data and inadequate understanding lead to uncertainty are the use of intermedia transfers--particularly biotransfer factors. Evaluation of methods for measuring and estimating these ITFs reveals that the ITF estimation methods have an error factor in the range of 1.5 to 10 (5). The overall variance in estimation methods for ITFs comes from several factors including variability among experiments; ignorance regarding the processes of chemical partitioning; and the reliability in measures of both the outcome (biotransfer or partition factor) and the explanatory variable (i.e., K_{OW}).

Future Directions

Exposure and health assessments are key steps in the analysis of a link between various incinerator sources and human health risks. If properly conducted and evaluated, these assessments can inform effective risk management strategies. Managing human exposures to the pollutants released from incinerators requires an assessment framework that addresses multiple sources and multiple exposure pathways. More important than an emphasis on predicting exposure and risk, this framework must be able to identify the most important pollutants, source categories and exposure pathways. An explicit treatment of the variability and uncertainty in the source to dose chain is necessary. As recently noted by Hertwich et al. (10), parameter, model, and decision rule uncertainty must all be addressed in multimedia exposure assessments.

If efforts to characterize incinerator health impacts are to be useful for decision makers and the public, two essential research tools, models and measurements, must be better integrated. Models provide the means to integrate and interpret measurements, design hypothesis-driven experiments, and predict the effectiveness of risk management strategies. Measurements, in turn, provide the tools evaluate and improve models.

BOX (this is quoted directly from the NRC press release)

In November 1999, the National Research Council, the operating arm of the U.S. National Academy of Science, released a report on the impact of waste incineration on public health. The report titled "Waste Incineration and Public Health" was the result of a multi-year study carried out by a multi-disciplinary team of experts and funded by three federal agencies, the U.S. EPA, the U.S. Agency for Toxic Substances and Disease Registry, and the U.S. Department of Energy. This report addressed the relationship between waste incineration and human health. This report provided a number of key findings, among them:

1) When operated properly by well-trained employees, modern waste incinerators pose little risk to public health. But older designs, human error, and equipment failure can result in higher-than-normal, short-term emissions that need to be studied further.

2) Based on the very limited studies on associations between incinerator emissions and health effects, no association has yet been made but the fact that ailments may occur infrequently or take years to appear, and the presence of pollution from other sources, make it difficult to determine if waste incineration can be blamed for local health problems.

3) Some studies have shown that workers at municipal waste incinerators, who can be exposed to emissions directly or when doing maintenance, have been exposed to high concentrations of dioxins and toxic metals, particularly lead, cadmium, and mercury, but follow-up studies were not performed to determine if this exposure caused disease.

4) Better epidemiological research is needed to assess the health risks of exposure to pollutants from incinerators, including studies that evaluate combined data from all incinerators in a particular area and that compare findings from similar facilities located in different regions studies of poorly performing facilities would be more valuable.

The report also calls for better data on the level of emissions that occur during start-up and shutdown, when they are likely to be greater. Sudden increases in emissions also can result from maintenance problems, accidents, a change in the composition of the waste being burned, and poor management of the incineration process. Furnaces designed for municipal-waste incineration prior to the mid-1980s are less efficient at combustion than newer designs. Modern plants often use auxiliary burners to maintain an optimal temperature during start-up and shutdown, though increased emissions can still occur. But with current technology, incinerators can achieve nearly complete combustion of the burnable portion of waste under normal operating conditions, emitting low amounts of unhealthy pollutants. In addition, using highly trained employees can help ensure maximum combustion efficiency and proper operation of emission-control devices.

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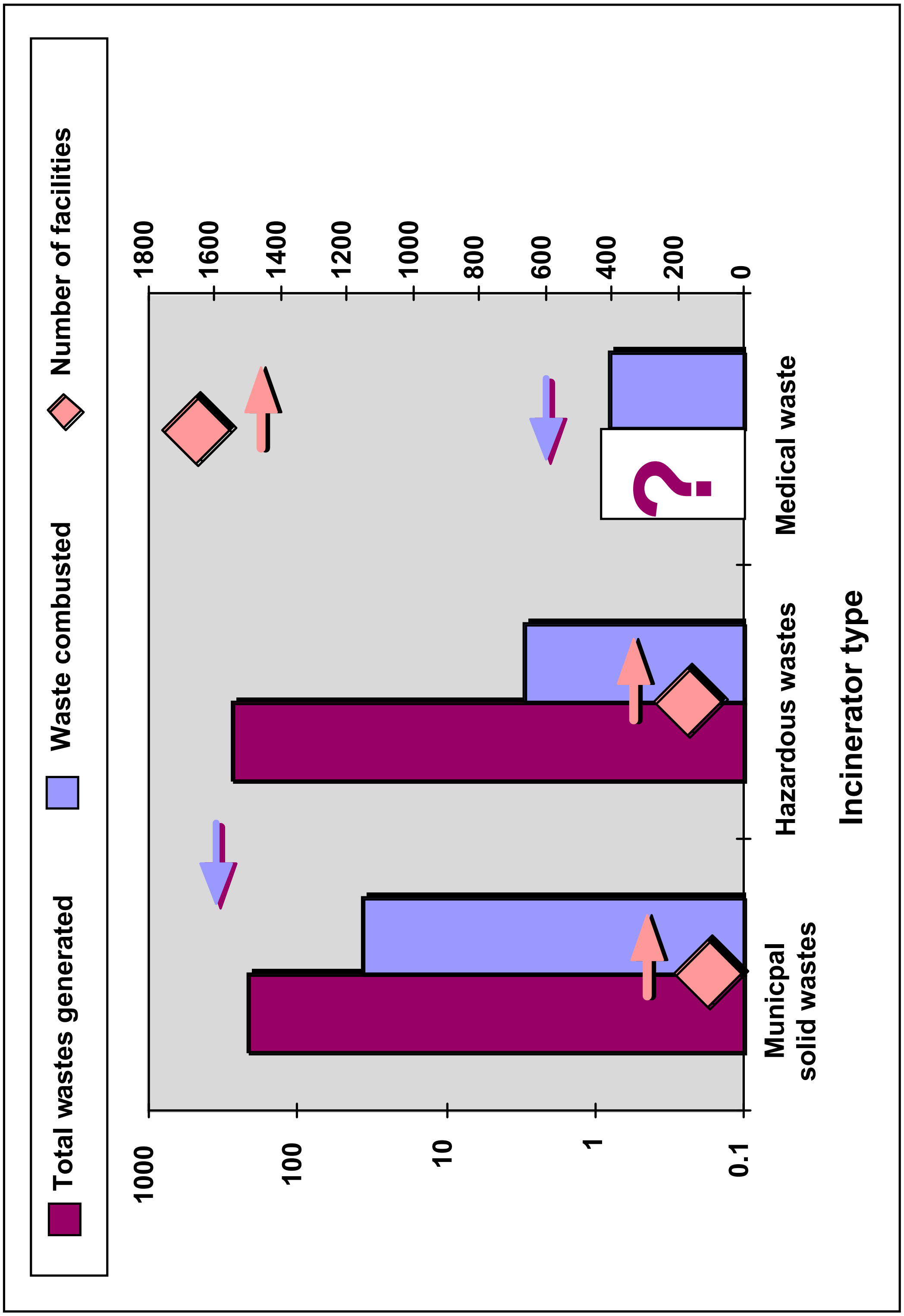
Figure Captions

Figure 1. Shown here for each of the major incinerator categories--municipal wastes, hazardous wastes, and hospital wastes--are the quantities of waste generated and the quantities of waste combusted along with the number of operating facilities available.

Figure 2. Many exposures to incinerator pollutants can have both a local and a regional sphere of impact. This map illustrates the complex link between cumulative indirect and direct exposures and multiple sources, which, for a given pollutant and receptor district, can include one or more local sources and multiple regional sources.



Total wastes generated
Waste combusted
Number of facilities
1000
100
10
1
0.1
1800
1600
1400
1200
1000
800
600
400
200
0
?
Municpal solid wastes
Hazardous wastes
Medical waste
Incinerator type

Figure 1

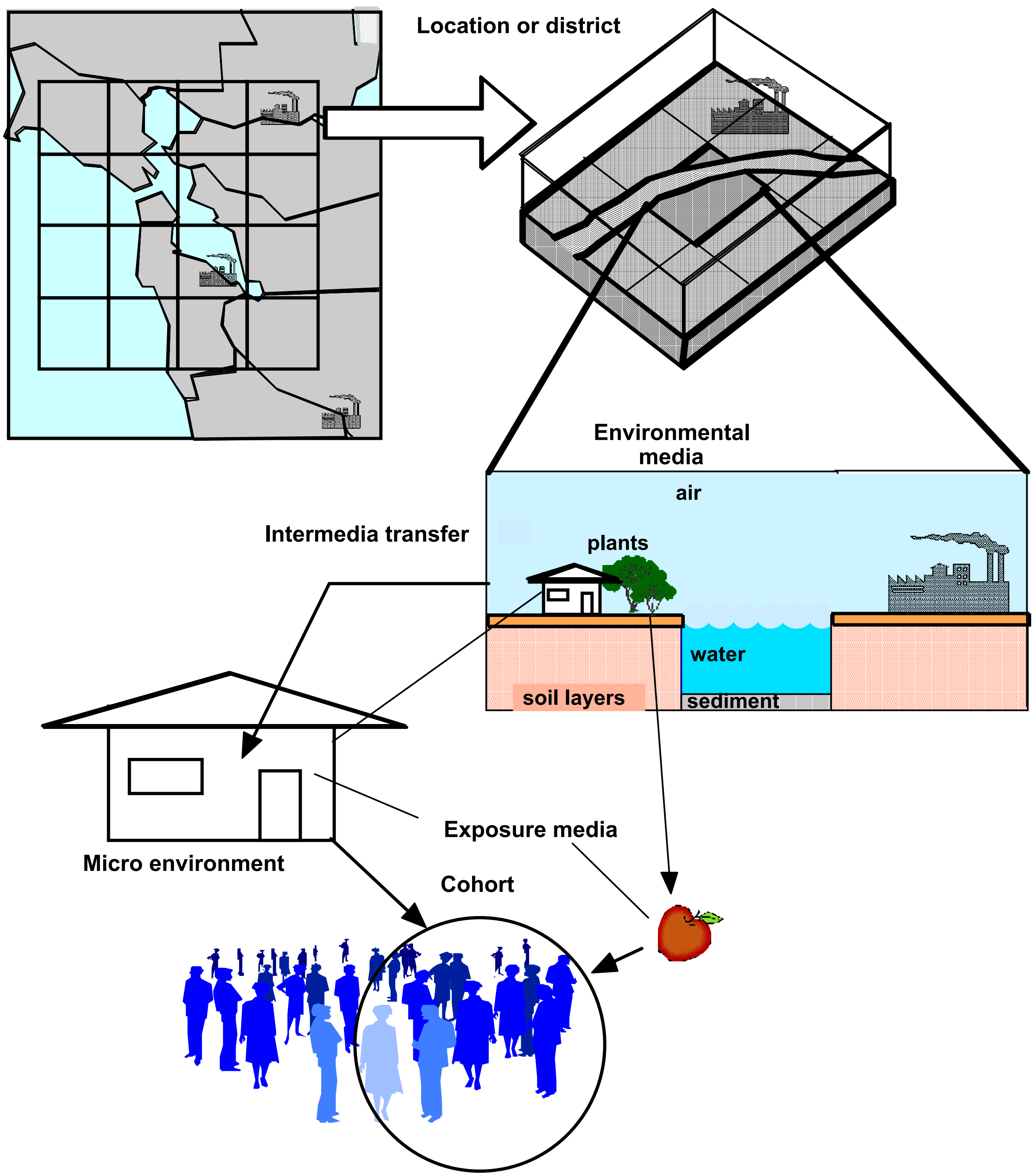

Location or district
Environmental
media
air
Intermedia transfer
plants
water
soil layers
sediment
Exposure media
Micro environment
Cohort

Figure 2.